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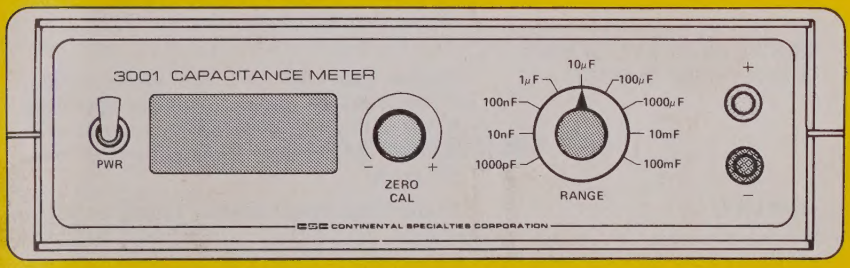
3001 DIGITAL CAPACITANCE METER



INSTRUCTION, OPERATION and APPLICATION MANUAL

MAINTENANCE

Congratulations!

You are part of the growing family of Continental Specialties Corporation test equipment owners. You now own a versatile and unique instrument offering extraordinary accuracy and full professional performance. To get the most out of your Model 3001 Digital Capacitance Meter, please read this manual carefully.

CSC CONTINENTAL SPECIALTIES CORPORATION

3001 SPECIFICATIONS

RANGE:	9 ranges, from 1999 pF to 199,900 μF full scale.
ACCURACY:	±0.1% of reading ±1 digit ±1 pF on 7 lower ranges; ±0.5% of reading ±1 digit on 2 upper ranges; determined at 23±5°C. Temperature coefficient of ±0.01%/°C applies to all ranges.
TECHNIQUE:	Measures $\Delta T/\Delta V_{th}$ (Dual Threshold slope integration).
EXCITATION VOLTAGE:	3.5 Volts maximum.
CONTROLS:	9-position Range switch, Power on/off switch. Zero Calibrate adjustment.
ZERO-CALIBRATE OFFSET ADJUSTMENT RANGE:	Greater than 100 pF. This allows nulling of any stray or cable capacitance appearing at the input, as when cable connects unit to high volume test fixture; permits max. 18" cable.
DISPLAY:	3½-digit high-brightness 0.5" character height LED.
OVERRANGE INDICATION:	Display flashes at approximately 2 Hertz.
UNDERRANGE INDICATION:	Zeroes displayed.
INPUT PROTECTION:	½ Amp 250 Volt fuse.
INPUT CONNECTION:	Twin banana jacks. See *Optional Accessories,* page 38 for optional plug-in connectors. (Plug-in spring-tensioned Test Clips and Test Cable included).
CALIBRATION ADJUSTMENT:	One internal range calibration adjustment.
POWER REQUIREMENTS:	105-125 VAC, 50/60 Hz, 6 Watts; 220-240 VAC, 50/60 Hz optional.
OPERATING TEMPERATURE:	5 - 45°C (40 - 110°F).
SIZE (WxHxD):	10" x 3" x 7" (254 x 76 x 178 mm).
WEIGHT:	3 lbs. (1.4 kg).

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3001 3½ DIGIT 0.1% DIGITAL CAPACITANCE METER SPECIFICATIONS									
NOMINAL RANGE	1000pF	10nF	100nF	1μF	10μF	100μF	1000μF	10mF	100mF
MINIMUM READING	1pF	10pF	100pF	1nF	10nF	100nF	1μF	10μF	100μF
MAXIMUM READING	1999 pF	19.99 nF	199.9 nF	1.999 μF	19.99 μF	199.9 μF	1999 μF	19.99 mF	199.9 mF
RESOLUTION	1pF	10pF	100pF	1nF	10nF	100nF	1μF	10μF	100μF
ACCURACY: % of READING # of COUNTS	±1pF ±0.1% ±1	±0.1% ±1	±0.1% ±1	±0.1% ±1	±0.1% ±1	±0.1% ±1	±0.1% ±1	±0.5% ±1	±0.5% ±1
MAXIMUM DELAY (midrange reading), seconds	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	3.5

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INTRODUCTION

The CSC Model 3001 Digital Capacitance Meter is a highly accurate precision test instrument designed specifically for professional use in design, quality control, inspection, production, calibration, service, scientific and laboratory applications.

It offers 3½-digit resolution, accuracy to 0.1% of the *reading* (not 0.1% of the *range,* which would be an inferior specification), and the capability of measuring capacitance from picoFarads to 0.1999 Farad.

It is designed to operate from the AC power mains, which eliminates entirely the problematic accuracy surrounding battery operated equipment.

Most capacitance readings appear within 0.3 seconds; the maximum for the highest range (worst case) is 3.5 seconds. Underrange and overrange indications are automatic.

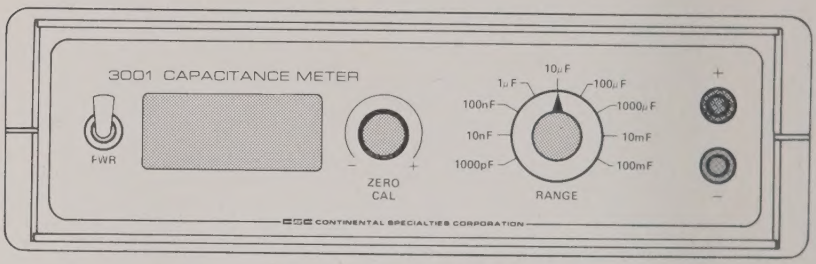
A front panel Zero Calibrate control permits stray and incidental capacitance, as might be associated with a cable lead to a test future, to be nulled out. This control is purposely placed away from the device test jacks to avoid the problem of hand-capacitance-induced errors and line-induced errors.

A special rear panel connector provides clock and gate signals to permit the interconnection of the 3001 with optional accessories for greater efficiency and utility in specified applications.

An expanding line of accessories is available to further enhance the value of the 3001.

Because of the Dual Threshold integration technique employed in the analog-to-digital (A/D) converter section of the 3001, errors induced by the dielectric absorption of some capacitors (see the discussion in *Appendix II*) are virtually eliminated.

Applications for the 3001 include sorting capacitors by value, selection of precision values, checking capacitor tolerances, matching sets of capacitors, quantifying unmarked capacitors, measuring cable capacitance, measuring cable length by capacitance, measuring the capacitance of switches and other electronic components, measuring the capacitive coupling between printed circuit traces or wires, measuring stray capacitance, measuring the capacitance of antenna components and systems, measuring the capacitance of networks, and demonstrating the physics of capacitance, especially in process control and educational/instructional applications.



FRONT PANEL

Power

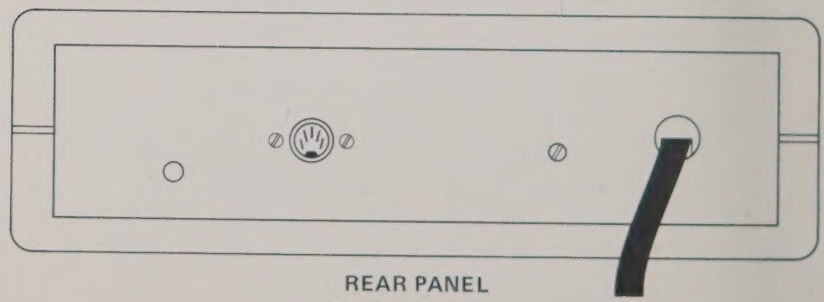
Toggle up for *on,* down for *off.* Display serves as pilot light.

Display

3½-digit 0.5" high-brightness LED display indicates capacitance reading within selected range. Entire display flashes to indicate overrange readings (greater than 1999 counts); zeroes displayed for underrange values. Decimal point position, controlled by range switch, permits direct translation between the range switch setting and the value displayed.

Zero Calibrate

Necessary when working with very small capacitance values to effectively null out incidental, spurious, stray and connecting cable capacitance, the Zero Calibrate control is used to adjust the 3001 display to read zero when no capacitor is connected. Adjusts clockwise for + (increasing displayed value), counterclockwise for – (decreasing displayed value).



REAR PANEL

COMPARISON OF CAPACITANCE UNITS

F = Farad	mF = milliFarad	μF = microFarad	nF = nanoFarad	pF = picoFarad
10^{0} 1	10^{3} 1000	10^{6} 1000000	10^{9} 1000000000	10^{12} 1000000000000
10^{-1} .1	10^{2} 100	10^{5} 100000	10^{8} 100000000	10^{11} 100000000000
10^{-2} .01	10^{1} 10	10^{4} 10000	10^{7} 10000000	10^{10} 10000000000
10^{-3} .001	10^{0} 1	10^{3} 1000	10^{6} 1000000	10^{9} 1000000000
10^{-4} .0001	10^{-1} .1	10^{2} 100	10^{5} 100000	10^{8} 100000000
10^{-5} .00001	10^{-2} .01	10^{1} 10	10^{4} 10000	10^{7} 10000000
10^{-6} .000001	10^{-3} .001	10^{0} 1	10^{3} 1000	10^{6} 1000000
10^{-7} .0000001	10^{-4} .0001	10^{-1} .1	10^{2} 100	10^{5} 100000
10^{-8} .00000001	10^{-5} .00001	10^{-2} .01	10^{1} 10	10^{4} 10000
10^{-9} .000000001	10^{-6} .000001	10^{-3} .001	10^{0} 1	10^{3} 1000
10^{-10} .0000000001	10^{-7} .0000001	10^{-4} .0001	10^{-1} .1	10^{2} 100
10^{-11} .00000000001	10^{-8} .00000001	10^{-5} .00001	10^{-2} .01	10^{1} 10
10^{-12} .000000000001	10^{-9} .000000001	10^{-6} .000001	10^{-3} .001	10^{0} 1

Range Switch

Selects one of nine capacitance ranges for measurement and display. While labelled in multiples of 10, actual ranges extend to 1999 counts to facilitate measurements near standard multiple-of-ten capacitor values with a minimum of range switching. Units are picoFarads (10^{-12} Farad), abbreviated pF; nanoFarads (10^{-9} Farad), abbreviated nF; microFarads (10^{-6} Farad), abbreviated μF; and milliFarads (10^{-3} Farad), abbreviated mF. The accompanying chart shows the relationship between these units.

Input Connectors

Standard banana jacks, spaced ¾-inch apart to accept either individual single or standard double banana plugs, attached to either clips or cables for quick, convenient testing.

Remote Interface (Rear Panel)

Special connector for remote display, sorting and control accessories. Both clock and gate signals are brought out at buffered TTL levels.

INITIAL INSPECTION AND CHECKOUT PROCEDURE

CAUTION!
Before proceeding, see *Precautions* in *Operating Instructions,* page 10.

In order to accomplish the initial inspection of your CSC Model 3001 Digital Capacitance Meter, you will need the following:

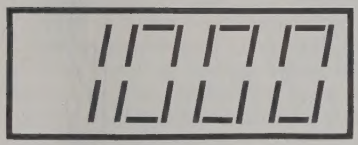
1. A grounded (3-prong) 50/60 Hz AC outlet.
2. A capacitor with a nominal value in each of the following ranges:
   a) 100 - 1000 pF
   b) .001 - .01 μF
   c) .01 - .1 μF
   d) .1 - 1 μF
   e) 1 - 10 μF
   f) 10 - 100 μF
   g) 100 - 1000 μF
   h) 1000 - 10,000 μF
   i) .01 - .1 F

   It is not absolutely necessary that you have all nine of these values. They will be used (a-i) to check out the lowest through highest ranges of the 3001, respectively.

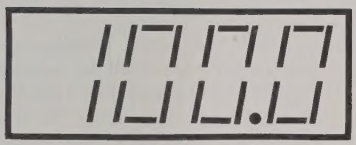
Procedure

1. Make certain nothing is connected to the 3001 Input terminals.
2. Plug the 3001 into the outlet. Turn the power switch *on.* The display should light.
3. Plug the capacitor Test Clip input accessory into the banana jack Input terminals. Connect nothing else. Try each of the range switch positions, leaving the switch in each position for at least ten seconds. In all but perhaps the first (lowest) range, the display should read 0000.*
4. Check for decimal point position. There should be no decimal point in the first and seventh ranges (0000); a decimal point between the third and fourth (reading from the left) digits in the third, sixth and ninth ranges (000.0); a decimal point between the second and third digits in the second, fifth and eighth ranges (00.00); and a decimal point between the first and second digits in the fourth range (0.000). In short, the number of digits* to the left of the decimal point is the same as the number of digits included in the range switch label for each range.

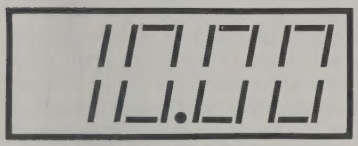
*Note: The leftmost zero may be blanked.



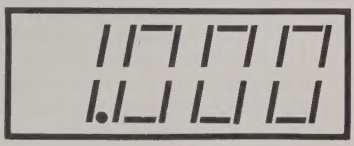
RANGES 1,7



RANGES 3,6,9



RANGES 2,5,8



RANGE 4

5. Adjust the range switch for the first (lowest, 1000 pF) range. Adjust the ZERO CAL knob randomly through its range. The display should vary from 0000 to 0100 or more.
6. CAUTION: Discharge each capacitor before use by shorting its leads together. In each range, from lowest to highest, try reading the value of the capacitors mentioned above in requirements 2-a through 2-i, respectively, as available. While the actual value measured may vary from the value marked on the capacitor by 2:1 or more, the reading in each instance should be in-range.
7. Also check one of the larger-value capacitors in one of the lower ranges. The display will flash (*overrange* indication), showing the capacitance value is overscale for the range.
8. Disconnect everything from the Input terminals, turn off the 3001, and disconnect from the AC power mains. This completes the Initial Inspection and Checkout Procedure. The initial inspection and checkout procedure for the rear panel Interface Connector is described in the Instruction and Operating Manual for CSC's Model 333 Tri-Mode Comparator.

OPERATING INSTRUCTIONS

Precautions

1. Fully discharge any capacitor to be measured *before* connecting it to the 3001.
2. Observe polarity when connecting polarized capacitors. Always connect the capacitor + lead to the ⊕ Input terminal (the top, red banana jack or the indicated Test Cable or Test Fixture connector or clip), the – lead to ⊖ (black banana jack).
3. *Do not* apply any Voltage to the Input terminals. Capacitance within a passive network must be measured with no power applied to it and with no retained Voltage present. (While the 3001 input *is* protected, serious internal damage *may* result from the charges present on large-value and high-Voltage capacitors, especially electrolytics).
4. Due to the high input impedance of the 3001, especially in its three lowest ranges, it is important to keep hands and other sources of power line pickup away from the Input terminals in order to assure an accurate reading. The lower the capacitance being measured, the more important this precaution. Pickup will cause the least significant digit (LSD, the rightmost digit) to flicker. Also see note 5, below.
5. It may be advantageous to shield the input with some sort of metal enclosure or metal shield, which should be connected to the ⊖ Input terminal. Also, when measuring physically large capacitors of small capacitance value, connect the ⊖ Input terminal to the capacitor electrode offering the most shielding; for example, the frame of an air variable or the shield of a coaxial capacitor.

Procedure

1. Set the Power switch to its *on* position. The display will light to confirm power-on.
2. Connect test leads or fixture to be used, maintaining proper polarity, as marked.
3. To null out the effects of cable and stray capacitance:
   a) Set Range switch to lowest (100 pF) range.
   b) Make sure no capacitor or device is attached to the Test Clips, Test Cable or Test Fixture to be used, and that the contacts are not touching. Then attach the Test Clips, Test Cable or Test Fixture to the 3001 Input terminals, observing polarity.
   c) Adjust the Zero Cal control until the display just reads zero at all digits.
   d) Adjust the Zero Cal control back and forth to ascertain best zero, which is just counterclockwise of the point where the display alternates between 0000 and 0001.*
   e) Movement of the Test Cable or Test Fixture may require a new Zero Cal setting.
4. Short out any charge retained in the capacitance to be measured.
5. Observe polarity when attaching the capacitance to the test lead or fixture.
6. Select the appropriate capacitance range, remembering that the full scale reading is *twice* the marked capacitance value indicated by the range switch; for example, full scale in the "10 μF" range is actually 19.99 μF. For unmarked or unknown capacitances, start at the lowest range and work up until a range is reached in which the display does not flash (overrange indication).

*Note: The leftmost zero may be blanked.

7. A flashing of the display (overrange indication) indicates that the capacitance being measured is higher than the maximum capacitance measurable in that range; this could also occur if the capacitor is exceptionally leaky. This flashing begins after approximately five seconds.
8. Because the capacitor may be first attached at some mid-point in the instrument's timing cycle, the very first reading may be inaccurate. Leave the capacitor attached long enough (0.6 seconds in 8 lowest ranges, 7 seconds in highest, 100 mF range) for two reading cycles to occur.

Considerations

1. **Test Leads.**

   Select test leads that are terminated in a standard, ¾-inch spaced double banana plug. A low-capacitance single-conductor shielded or coax cable is preferred, with the shield connected to the ⊖ terminal. Use short test leads, maximum 18 inches (assuming RG-58/U). The 3001 will cancel out more than 100 pF of lead and stray capacitance.

2. **Zero Calibration.**

   Recheck the zero calibration of the 3001 each time the instrument is used, and periodically during long-term use. (Note: the Zero Calibration control is disabled above the three lowest ranges). See *Procedure,* step 3. Rotation of the Zero Cal control below the zero point (display still reads 0000) will cause subsequent readings to be low.

3. **Open Capacitors.**

   An open capacitor will read zero on all ranges, or may possibly read a few pF on the lowest range.

4. **Shorted or Leaky Capacitors.**

   A shorted capacitor will flash the display (overrange indication) on all ranges; an excessively leaky capacitor will read far above its actual value.

5. **Input Protection Fuse.**

   An internal fuse protects the 3001 input from damage by charged capacitors. If, for some reason, the fuse blows, the 3001 will read ZERO for *all* capacitors. To replace the fuse (type 3AG, ½ Amp, 250 Volt), which is located inside the unit, on the PC board, near the Input terminals, see instructions for disassembling the 3001 case in the *Maintenance and Calibration* section (page 26).

6. **Capacitor Voltages.**

   The 3001 applies a maximum of 3.5 VDC to the capacitor (capacitance) being measured; on the two highest ranges this is 0.5 VDC. As a result, there is *no* danger of exceeding the Voltage rating (WVDC) of any capacitor, and *no* danger of a capacitor retaining a dangerous charge when removed from the instrument.

When a capacitor is charged by a known current from one defined Voltage level to another, the time interval between the two Voltages is directly proportional to the capacitance being charged.

Defining Deltas

Defining the Voltage levels as a high threshold, $V_{th(HI)}$, and a low threshold, $V_{th(LO)}$, the Voltage interval, ΔV_{th}, becomes:

$$\Delta V_{th} = V_{th(HI)} - V_{th(LO)}$$

Labeling the times at which the Voltage V_{Cx} (across capacitance, C_x) equals the threshold Voltages:

$$t_{C(LO)} = t_C \text{ at } V_{th(LO)}$$
$$t_{C(HI)} = t_C \text{ at } V_{th(HI)}$$

And the time interval, Δt_C, during which C_x charges from $V_{th(LO)}$ to $V_{th(HI)}$ becomes:

$$\Delta t_C = t_{C(HI)} - t_{C(LO)}$$

By definition, the value of a capacitance is determined by the amount of charge (expressed as the number of electrons, in coulombs) it retains at a given Voltage:

$$\text{Capacitance (Farads)} = \frac{\text{Charge (coulombs)}}{\text{Voltage (Volts)}}$$

A coulomb is defined as approximately 6×10^{18} electrons (see *Appendix II*, page 34).

Since current is defined as the rate of charge transfer:

$$\text{Current (Amperes)} = \frac{\text{Charge (coulombs)}}{\text{Unit time (second)}}$$

And since the charge required to change the Voltage across a capacitor by a fixed amount (ΔV_{th}) is a function of the Capacitance:

$$\text{Voltage (Volts)} = \frac{\text{Charge (coulombs)}}{\text{Capacitance (Farads)}}$$

Then defining a constant* current level defines the interval of time (Δt_C)

**Even though the 3001 does not use a constant current source, the proportionality remains valid. The actual relationship is logarithmic:*

$$C = t \left(1/R \left[\ln \left(\frac{V_{Ref} - V_{th(LO)}}{V_{Ref} - V_{th(HI)}} \right) \right] \right)$$

TERMS USED IN EXPLANATIONS OF 3001 OPERATIONS

C_s	Stray capacitance, including cable, fixture, spurious, etc.
C_x	Capacitance to be determined by measurement
C_T	Total capacitance appearing at 3001 Input terminals
R_t	Charging (time constant determining) resistor
t	Time
t_C	Capacitor charging time
Δt_C	Capacitor charging time interval
$t_{C(LO)}$	Time t_C when $V_{Cx} = V_{th(LO)}$
$t_{C(HI)}$	Time t_C when $V_{Cx} = V_{th(HI)}$
t_G	Time during which the timing gate is active, $t_G = t_{C(HI)} - t_{C(LO)}$
$t_{G(CE)}$	Time t_G during which Clock Enable (CE) is active
V_{Cx}	Voltage appearing across capacitor C_x
V_{Ref}	Reference Voltage (rail, 5VDC)
V_{th}	Comparator threshold Voltage
$V_{th(LO)}$	Lower threshold Voltage
$V_{th(HI)}$	Upper threshold Voltage
ΔV_{th}	Voltage interval between lower and upper thresholds

required to transfer a given charge:

$$\text{Charge (coulombs)} = \text{Current (Amperes)} \times \text{Unit time (seconds)}$$

Therefore under a defined constant charging current, the time required for a given change in the Voltage across a capacitor becomes:

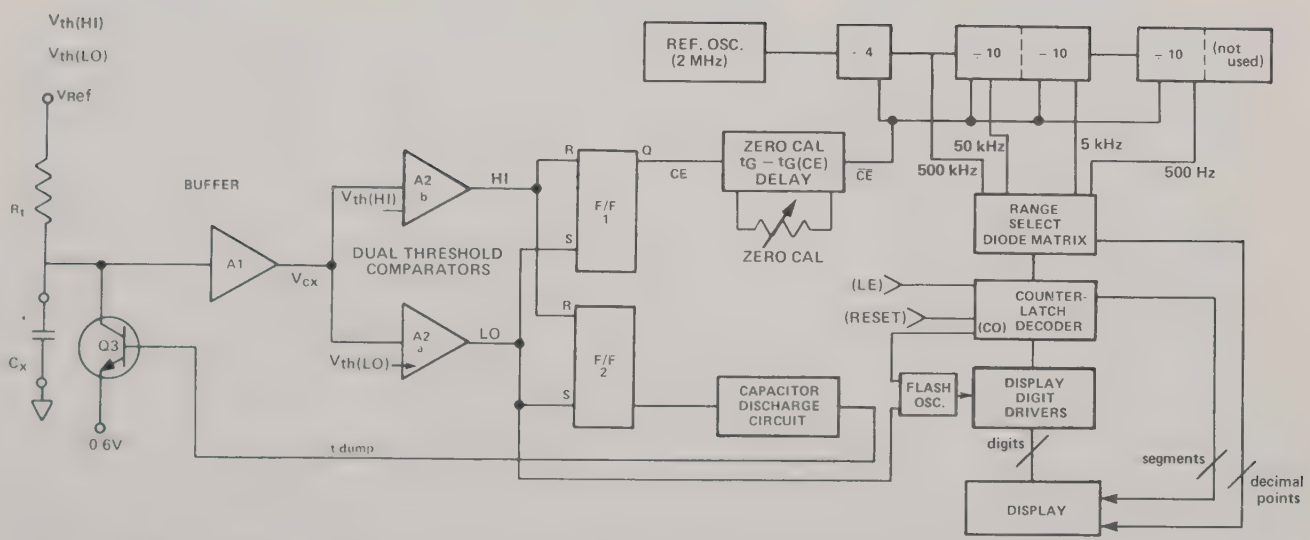
$$\text{Voltage (Volts)} = \frac{\text{Current (Amperes)} \times \text{Unit time (seconds)}}{\text{Capacitance (Farads)}}$$

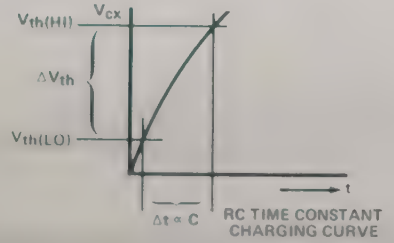
Restating this relationship in terms of capacitance:

$$\text{Capacitance (Farads)} = \frac{\text{Current (Amperes)}}{\text{Voltage (Volts)}} \times \text{Unit time (seconds)}$$

So, by precisely defining the Voltage interval and the current flow:

Capacitance can be shown to be proportional to the charging time interval.





BLOCK DIAGRAM
MODEL 3001 DIGITAL CAPACITANCE METER

The Charging Curve.

The curve shown adjacent to the block diagram demonstrates the change of Voltage (V_{Cx}) across a capacitance (C_x) versus time (t_C) when the capacitance is charged by a constant current.

We will mark two points of interest on the curve. The first is the time ($t_{C(LO)}$) when the Voltage across the capacitor is equal to the lower of two defined threshold Voltages ($V_{th(LO)}$); the second is the time ($t_{C(HI)}$) when it is equal to the higher threshold Voltage ($V_{th(HI)}$).

When the charging current is constant, the rate of charge flow is constant. And since the Voltage across the capacitor (V_{Cx}) is defined as charge per unit capacitance, the change in Voltage (ΔV_{th}) required to charge from $V_{th(LO)}$ to $V_{th(HI)}$ is defined as change in charge per unit capacitance. Since change in charge per unit time is current, and the current is constant, by holding $V_{th(LO)}$ and $V_{th(HI)}$ constant, the time required to traverse ΔV_{th} (which is $t_{C(HI)} - t_{C(LO)}$ or Δt_C) provides a directly proportional indication of the capacitance at C_x.

In short, the larger the capacitance, the longer it will take to charge it from some defined Voltage to another, and by measuring this time interval, we have a measure of the capacitance.

The Block Diagram.

Capacitor C_x is charged to Voltage V_{Cx} through resistor R_t from fixed reference Voltage $V_{Ref.}$ The capacitance actually measured is a combination of the intended measurement and stray or incidental capacitance:

$$C_T = C_x + C_s$$

Two comparators monitor V_{Cx} and trigger when it crosses $V_{th(LO)}$ and $V_{th(HI)}$, respectively. These comparators start and stop the digital circuitry which measures the time interval Δt required to cross the voltage interval ΔV_{th}:

$$\Delta V_{th} = V_{th(HI)} - V_{th(LO)}$$

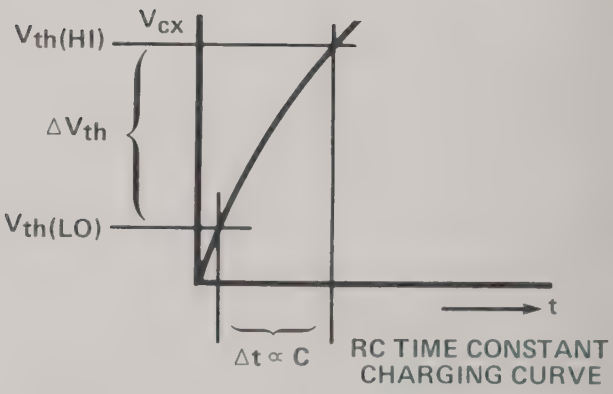
The comparators open and close a timing gate. In the three lowest ranges, the clock enable (CE) signal is delayed by the Zero Calibrate circuit and control in order to null out precisely any measurement caused by C_s.

At the end of the timing cycle, transistor Q3 discharges C_x fully, to a slightly negative Voltage, and remains on for a fixed delay period even after V_{Cx} discharges below $V_{th(LO)}$. This assures full dumping of all retained charge, including that caused by dielectric absorption. As a further precaution, the measurement starts anew at the crossing of $V_{th(LO)}$ rather than immediately upon turn-off of the discharge transistor, as in single-threshold approaches.

In the following discussion of the circuit of the CSC Model 3001 Digital Capacitance Meter, refer to the **Schematic**, *page 20.*

The 3001 operates by measuring the time it takes for a given capacitance to charge between two Voltage reference points. Since this time is directly proportional to the magnitude of the measured capacitance, appropriate scaling of the various parameters permits direct digital readout of capacitance in standard units.

The Input section of the 3001 is analog in nature. Its analog signals are compared to references to generate gating signals for the digital display section and its associated clock, counter, latch and decoder circuitry.



RC TIME CONSTANT CHARGING CURVE

Input Section

The capacitance being measured is C_x. An appropriate value of R_t, selected by the Range switch, charges C_x. Q3 is switched on to discharge C_x whenever V_{Cx}, the Voltage appearing across C_x, exceeds $V_{th(HI)}$.

The charging cycle begins once Q3's charge dumping cycle is complete. As C_x charges, V_{Cx} (buffered by A1) will cross first $V_{th(LO)}$, then $V_{th(HI)}$.

Comparators A2-a and A2-b act together as a Dual Threshold window comparator. A2-a turns on when V_{Cx} exceeds $V_{th(LO)}$, which provides a *set* signal for flip-flop F/F-1; A2-b turns on when V_{Cx} exceeds $V_{th(HI)}$, which *resets* F/F-1 and F/F-2.

F/F-1 provides a Clock Enable (CE) signal to the digital display portion of the circuit. In the 3001's three lowest ranges, the ZERO CAL circuit delays the arrival of the CE gate to allow the effects of stray and incidental capacitance to be nulled out (see *Functional Description,* p. 12).

F/F-2 controls the CAPACITOR DISCHARGE circuit, which controls Q3. Q3 turns on as soon as V_{Cx} reaches $V_{th(HI)}$, and stays on as C_x discharges until V_{Cx} reaches $V_{th(LO)}$. Then, to assure that the *reset* signal to the counter does not occur simultaneously with the *latch enable* (LE) signal, R35 and C7 provide an additional 20 μsec delay, still keeping Q3 on. Finally, at the end of this delay, F/F-2 is *set,* initiating an additional delay of either 0.1 or 1.0 second (depending on the Range Switch setting) before Q3 is permitted to turn off and the next charging cycle begins. This insures complete discharge of C_x, assures that the charging cycle begins well below $V_{th(LO)}$, and obviates the effects of dielectric absorption.

Display Section

The 2.0 MHz crystal oscillator, U8-a, provides the basic timing reference for the digital portions of the circuit. A string of dividers (U-4, U-5 and U-6) provide the 500kHz, 50kHz, 5kHz and 500Hz clock frequencies which are selected by the Range Select diode matrix and U9.

The clock signal is applied to U7, a single-chip 3½-digit counter, latch and decoder IC, including the display segment drivers.

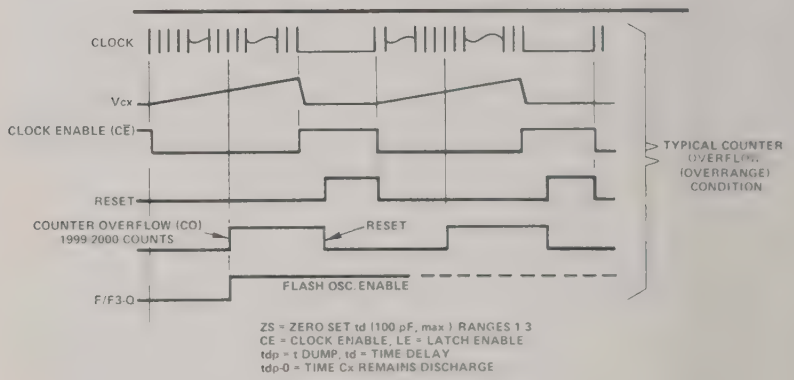
Gating for U7, as previously discussed, is supplied from A2, the Dual Threshold window comparator; R35, C7, D3 and U3-a provide the necessary delay between *latch enable* and *reset* commands.

If U7 overflows before $V_{th(HI)}$ is reached, the *carry out* signal triggers the FLASH OSCILLATOR circuit, U8-c, U3-b, and Q18, which flashes the entire display (except the decimal point) at a 2 Hz rate.

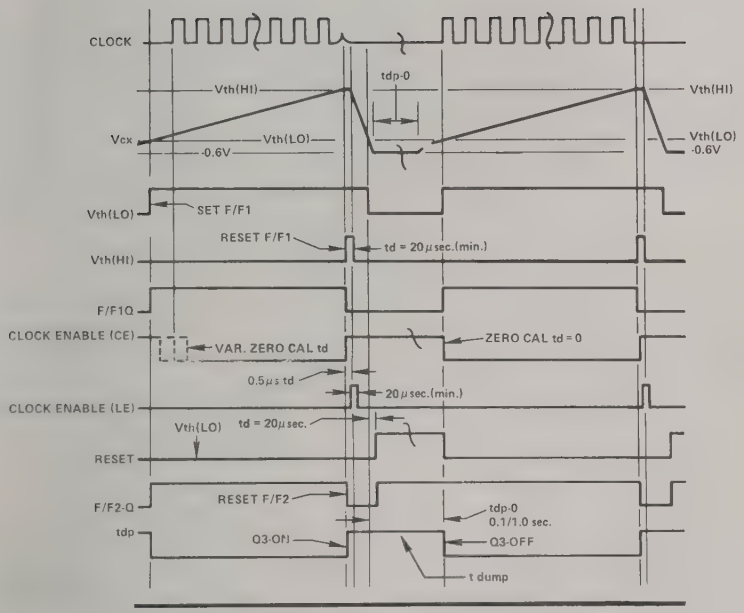
The Range Select diode matrix also determines which, if any, of the decimal points will be illuminated. This diode matrix also selects the value of R_t (through Q1 and Q2); the length of the t_{dump} interval (through U2-d and Q9); whether or not the ZERO CAL delay circuit, monostable U2-c, R37 and C9 will be disabled (through Q8); and the values of $V_{th(HI)}$ and $V_{th(LO)}$ (through Q5 and Q6).

The display is a 3½-digit 0.5-inch seven segment LED. Segments are driven directly by U7, while digits are driven through Q13-16. Q10-12 are the decimal point drivers.

Regulated reference and supply Voltages are provided by A3 and A4, three-terminal regulator ICs, and A5, a three-terminal negative regulator IC. D7, D8 and Q7 provide the –0.6VDC discharge reference for dump transistor Q3.



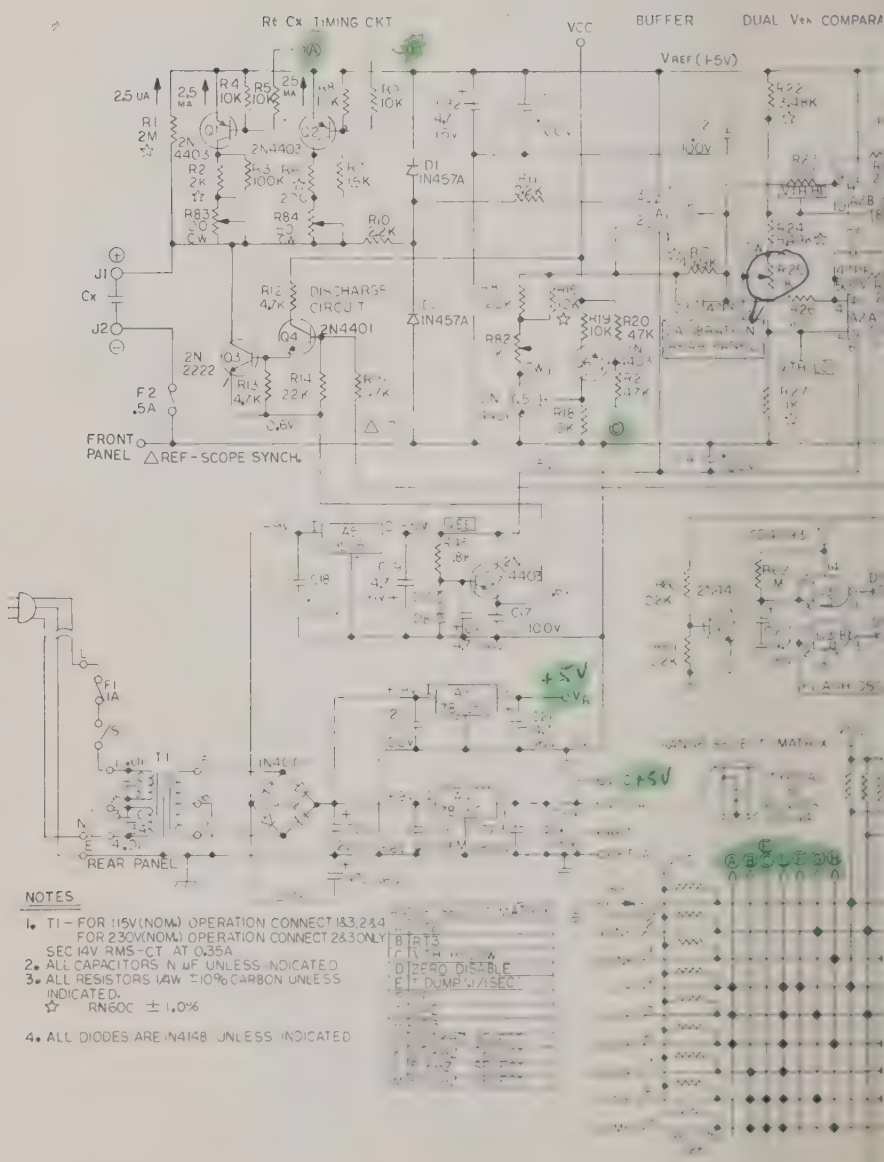
OVERFLOW CONDITION



MODEL 3001 TIMING DIAGRAM

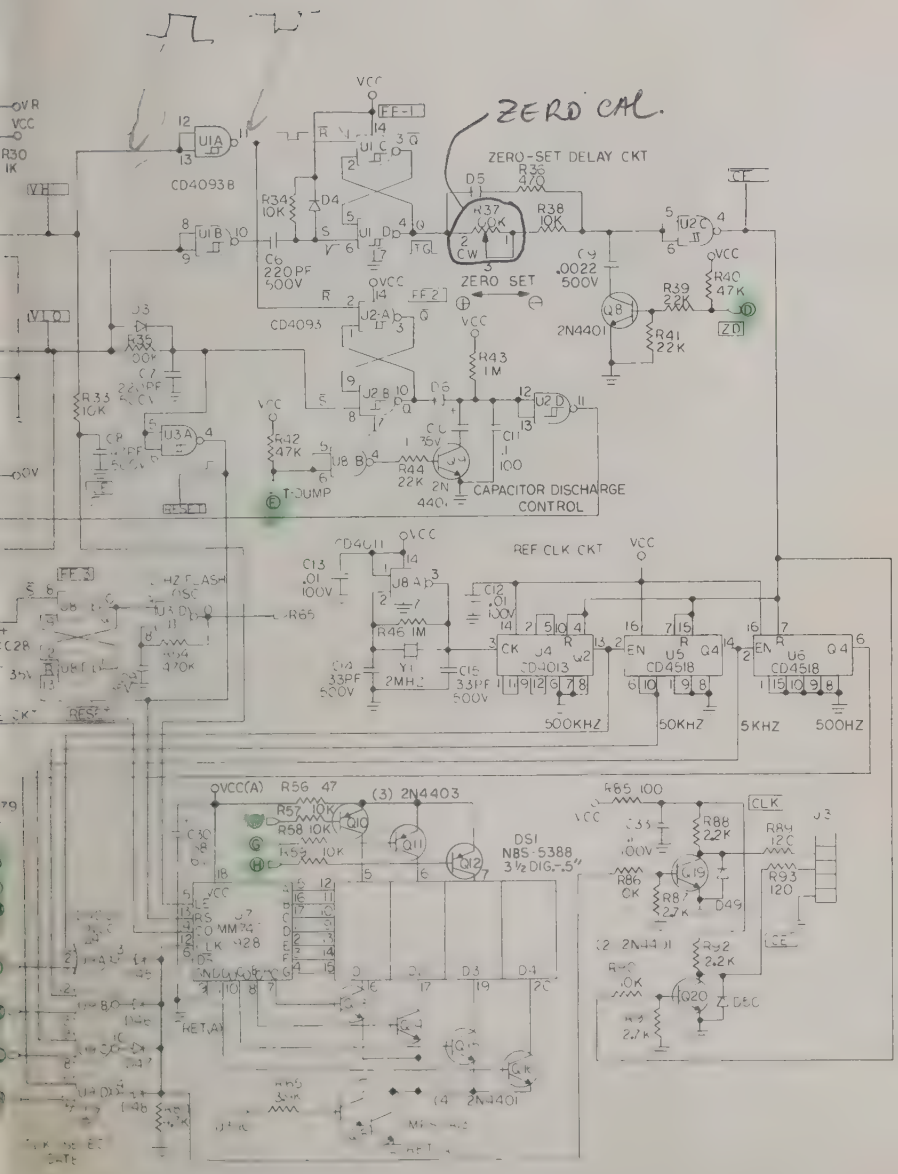
A1 = LE 356
A2 = LM 319

SCHEMATIC



NOTES

1. T1 – FOR 115V(NOM.) OPERATION CONNECT 1&3, 2&4
   FOR 230V(NOM.) OPERATION CONNECT 2&3 ONLY
   SEC 14V RMS-CT AT 0.35A
2. ALL CAPACITORS IN uF UNLESS INDICATED
3. ALL RESISTORS 1/4W ±10% CARBON UNLESS INDICATED.
   ☆ RN60C ±1.0%
4. ALL DIODES ARE 1N4148 UNLESS INDICATED


ZERO CAL.
ZERO-SET DELAY CKT
ZERO SET
CAPACITOR DISCHARGE CONTROL
REF CLK CKT
CD4011
CD4013
CD4518
CD4093B
CD4093
500KHZ
50KHZ
5KHZ
500HZ
(3) 2N4403
DSI
NBS-5388
3½ DIG.-.5"
2N4401
VCC
CLK

APPLICATIONS

The CSC Model 3001 Digital Capacitance Meter serves many classes of applications because it measures not simply the values of capacitors, but of any form of capacitance. Since capacitance is an electrically measurable physical property that exists between any two conductive surfaces that are not electrically connected, a variety of new application areas are available. The following is a brief survey of several popular applications for the 3001.

Quality Control/Inspection

1. **Sorting capacitors by value, grading.**

   In many laboratory and production situations, it is important to know whether or not a capacitor is within a given percentage of its nominal (marked) value; for some applications, precision is crucial, for others it is not. A given assortment of capacitors with the same nominal value can easily be sorted as to which fall within 1%, 2%, 5%, 10%, 20% or any given percentage by setting the range limits mathematically:

   $$\text{Limits} = \text{Target Value} \times \left(1 \pm \frac{\text{percentage}}{100}\right)$$

   For example, for 5% tolerance on a 400 pF capacitor:

   $$\text{Limits} = 400 \times \left(1 \pm \frac{5}{100}\right) = 400 \times (1 \pm .05)$$
   $$= 400 \times (.95, 1.05) = 380, 420 \text{ pF}$$

2. **Selection of precision values.**

   Precision capacitance values may be selected from an assortment of non-precision capacitors near the target value using the 3001. Also, the 3001 can be used to inspect precision capacitors to ascertain whether or not the actual value agrees with the specified value.

3. **Checking capacitor tolerances.**

   Nominal capacitor values are notoriously ill-defined; specifications of +80%/-20% are not uncommon. The actual tolerance of any given group (or subgroup) of capacitors can be determined by measuring their actual capacitance with the 3001 using the formula:

   $$\% \text{ Tolerance} = \frac{(\text{Measured value} - \text{Nominal value}) \times 100}{\text{Nominal value}}$$

4. **Matching sets of capacitors.**

In many applications, balanced or equal capacitor or capacitance values are more important than absolute value. The 3001 can be used to exactly quantify the value of each capacitor. This value can then be either tagged onto the capacitor or logged against a previous tag number. Also, progressive sorting techniques can provide the optimum yield of matched sets of capacitors within any tolerance requirement.

5. **Quantifying unmarked capacitors.**

In quantifying, or providing a numerical value for unmarked capacitors and capacitances, begin by performing the zero calibration procedure described under *Operating Instructions,* page 9. It is expedient to begin on the 3001's lowest range and work upwards, then taking the measurement in the first range in which the display does not flash (overrange indication) for best accuracy. As a double check, the capacitance could be measured in the next higher range, but with reduced resolution.

6. **Measuring cable capacitance.**

Since cables are, by definition, comprised of conductive elements which are not electrically connected to each other (within the cable), cables exhibit capacitance. Furthermore, complex cables (more than two conductors) are capacitor networks. The most useful measurements of cable capacitance are usually expressed in terms of capacitance per unit length between given pairs of conductors. This can be determined directly by the 3001 by providing a cable of precisely unit length (usually 1 foot or 1 meter) and reading its capacitance, after carefully nulling out the incidental capacitance of any interconnecting test leads, fixtures or connections with the zero calibration procedure (see *Operating Instructions,* page 9). Similarly, this may be determined for any length of cable with this formula:

$$\text{Capacitance per unit length} = \frac{\text{measured capacitance}}{\text{Number of units of length}}$$

7. **Measuring cable length by capacitance.**

If the capacitance-per-unit-length characteristic of a cable is known (or is determined as described in *Measuring cable capacitance,* above), capacitance measurement with the 3001 may be used to provide a measurement of the length of the cable using this formula:

$$\text{Cable length} = \frac{\text{Measured capacitance}}{\text{Capacitance per unit length}}$$

8. **Cable flaw detection by capacitance measurement.**

A cable of known length and capacitance per unit length may be inspected for taps, breaks or physical distortion by comparing the capacitance measured by the 3001 to the capacitance determined by calculation with the formula:

Capacitance = (Cable length) x (Capacitance per unit length)

A lower capacitance indicates an open conductor; a higher capacitance indicates severe crimping or insulation failure. The distance to a break can be determined as described in *Measuring cable length by capacitance,* above. It should be noted that unauthorized taps into a cable can be determined, but not located, by these techniques.

9. **Capacitance between printed circuit traces.**

Parallel traces on a printed circuit board, whether or not the same side of the board, exhibit capacitance. This can variously cause ringing, propagation delays, parasitic oscillation, unintentional noise and signal coupling, loading and other effects. The printed circuit designer can usually save time by troubleshooting for capacitive effects with actual capacitance measurement using the 3001 and a prototype printed circuit, as compared to calculation; this also provides a more practical real-world test. Alternatively, the 3001 could be used in conjunction with traces of known geometry on the planned pc board stock to determine the dielectric/capacitive nature of the specific board material. Also, the 3001 could be used for inspection of printed circuit board traces using the technique outlined in *Cable flaw detection by capacitance measurement,* provided traces of known capacitance within the accurate measurement range of the 3001 are present. This often applies to printed circuits involving even small numbers of digital integrated circuits; investigation of the suitability of these techniques to any specific application is recommended.

10. **Measuring the capacitance of switches, relays and other electronic components.**

There are a number of electronic components which exhibit capacitance out-of-circuit, including switches, relays, connectors, transformers, liquid crystal displays, quartz crystals, some microphones, antennas and more. There are two ways in which capacitance measurement might be gainfully applied to these components: First, as a means of determining the component's capacitive reactance versus frequency, and thus its suitability at any given frequency in a real or virtual network of components of various impedance values (for example, a reed switch or reed relay may be found to pass too much signal when open above a given frequency, or attenuate a signal too much, depending on the circuit configuration). Second, since capacitance between conductive elements of fixed geometry varies with their spacing, capacitive testing of passive components (keyboard switches, membrane switches or displays, for example) can be used to determine whether or not the units meet given criteria for several parameters, including arcing point, Voltage breakdown, capacitive loading and more.

11. **Transducer applications of physical capacitance.**

Two parallel conductive plates in space which are not electrically connected exhibit a capacitance (in picoFarads) according to the formula:

$$C = 0.224 \frac{KA}{d}$$

where K is the dielectric constant of the material between the plates, A is the area of one side of one plate (expressed in square inches), and d is the distance separating the "inner" (closest) surfaces of the plates. For interleaved groups of plates, where alternate plates are electrically connected and there are a total of n such plates, the formula becomes:

$$C = 0.224 \frac{KA}{d} (n-1)$$

Air has a dielectric constant of approximately 1; common window glass has a dielectric constant of about 8. It can been that these formulae might be applied to metallic or conductive materials in the real world to take advantage of capacitance as a means of indicating variations in geometry. For example, plates of known area but with variable separation will produce variations in their capacitance, which are measurable by the 3001. This separation distance, depending on the materials involved and the mechanics of attachment, could be used as a measure of air pressure, fluid pressure, position, displacement, and so on. Further, plates kept a fixed distance apart but made to move in the plane of the their (parallel) area could similarly be applied as position transducers. It can be seen that these noncontacting transducers offer several advantages in terms of contact wear, and thus reliability. And while a number of capacitive transducers are commercially available, and a number of standard components (such as capacitor microphones and variable capacitors) can be used as transducers, the user may readily provide his own conductive surfaces within the specialized framework of any custom application. In all of these cases, the 3001 provides a precise digital indication of the amount of capacitance at the transducer.

Alternate Inputs to the 3001

The user may provide connections to the 3001 input terminals other than through the accessory connectors available from CSC provided the following conditions are met:

1. No Voltage is present at the 3001 Input terminals.
2. Total connection capacitance between the test terminals and the 3001 is under 100 pF.
3. Polarity is maintained.
4. Standard banana plugs (or standard 3/4-inch-center dual banana plugs) terminate the interconnection and plug into the 3001.

Alternate Outputs from the 3001

The 3001 back panel interface connector is designed specifically for use with CSC accessories; the user, however, at his own risk, may elect to take advantage of the signals present there. These are *Ground, Gated Clock* and *Clock Enable* (CE) *Gate,* and are presented at a standard TTL level sufficient to drive, at minimum, one TTL load.

Fuse Replacement

The CSC Model 3001 Digital Capacitance Meter uses two fuses:

1. **Input Protection Fuse.**

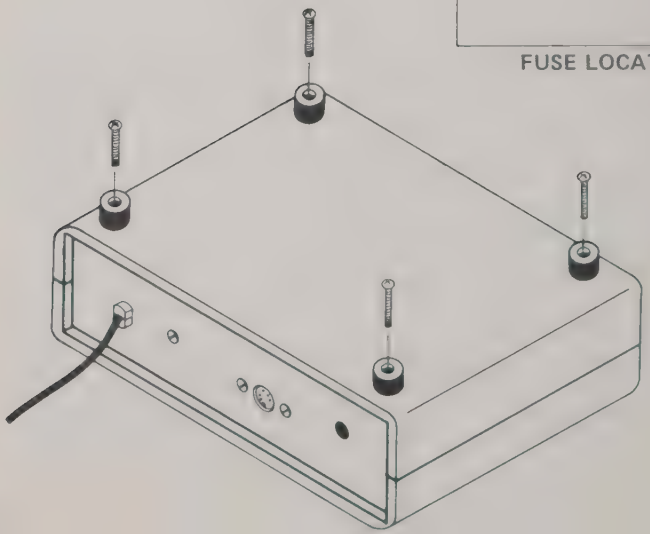
   Type 3AG, ½ Amp, 250 Volt. Located inside the case, clip-mounted to printed circuit board toward the front of the case, near the Input terminals.

2. **Power Supply Fuse.**

   Type 3AG, 1 Amp, 250 Volt. Located inside the case, clip-mounted to printed circuit board toward the rear of the case, near the power cord.

They may be replaced by the user, if, for any reason, replacement becomes necessary following this procedure:

1. Disconnect anything plugged into the Input terminals of the 3001.
2. Make certain the Power switch is *off.*
3. Disconnect the power cord at the AC outlet, not at the case or elsewhere.
4. Open the case, following the instructions under *Case Disassembly* (below) completely.
5. Use a non-conductive fuse handling tool to safely remove and replace either fuse. Make certain only to use a replacement fuse of equal size and rating.
6. To close the case, follow the instructions under *Case Reassembly* (below) completely.
7. Reattach the Power Cord to the AC outlet.
8. The 3001 is again ready for use.



FUSE LOCATIONS

Case Disassembly

Follow these steps any time you wish to open up the case of the 3001:

1. Remove any connections from the Input terminals.
2. Remove the AC Power plug from your AC outlet.
3. Turn the 3001 case upside down (feet facing up).
4. Remove the Phillips-head screw completely from the center recess of each of the four feet.
5. Keeping the top and bottom case halves together with light pressure, carefully reinvert the case so it is again upright.
6. Gently slide the upper half of the case straight upward; when clear of the front and rear panels, place it to one side.
7. The component side of the printed circuit board should now be visible, secured to the bottom half of the case and both front and rear panels.

Case Reassembly

Follow these steps to reclose the 3001 case:

1. Make sure no tools or debris remain inside the case, that all power and input connections are removed, and that the printed circuit board, front and rear panels are securely in place.
2. With the bottom case half upright, gently slide the upper case half straight down into position atop the lower half; make sure the front and rear panels are in position in the molded case panel grooves.
3. Once the top case half is in place, keep the case halves together, in position, with light pressure as you invert the 3001 case (placing it upside down, feet up).
4. Make sure all four feet are positioned directly over the holes in the case bottom.
5. Reinsert each of the four Phillips-head screws through the center hole in the recessed area of each foot and through the corresponding mounting holes in the case bottom into the threaded mounting posts molded into the upper case half.
6. Tighten all four screws, being careful not to overtighten.
7. Reinvert the 3001 to its upright position.
8. Reattach AC power. The 3001 is again ready for use.

Recalibration Procedure.

> **WARNING!**
> Calibration must be performed only by experienced technical personnel, and only using calibrated capacitance standards with 0.1% accuracy or better. Use of lesser standards will degrade the calibration accuracy of the 3001.

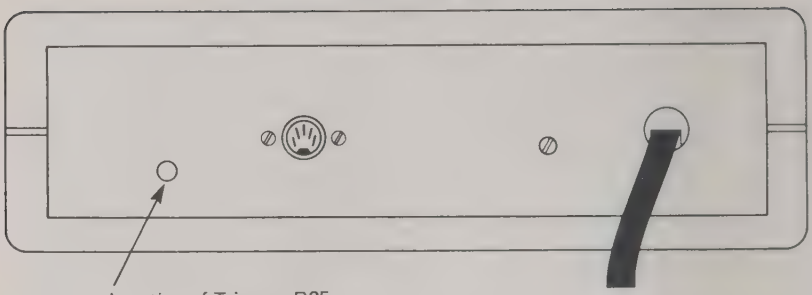
The 3001 was carefully checked and calibrated at the factory prior to shipment; recalibration should be performed only if the calibration of the instrument becomes suspect.

Four standard capacitance values are adequate for calibration over all nine ranges of the 3001:

1. A 1000pF±0.1% capacitor will calibrate the 1000pF, 10 nF and 100 nF ranges.
2. A 1.000μF±0.1% capacitor will calibrate the 1μF, 10μF and 100μF ranges.
3. A 1000μF±0.1% capacitor will calibrate the 1000 μF range.
4. A 10,000μF±0.1% capacitor will calibrate the 10mF and 100 mF ranges.

Known capacitances near these values may also be used. If capacitor value is first determined by a precision, laboratory-type capacitance bridge, it is important that electrolytics and other capacitors with high dissipation factors be evaluated with the bridge operating at its lowest frequency, usually 60 or 120 Hertz.

REAR PANEL



All adjustments are made to R25, a screwdriver-adjustable trimmer, accessible through a calibration hole in the rear panel of the 3001 *without case disassembly.*

Follow this procedure in recalibrating the 3001; ambient temperature should be 25±2°C, and the 3001 should be allowed an hour warm-up.

1. Set Range switch to 1000 pF range.
2. Attach test leads, but not capacitor, to Input terminals.
3. Adjust ZERO CAL control to null out test lead capacitance, following instructions in *Operating Instructions* section of this manual (page 10).
4. Connect the 1000 pF ± 0.1% standard capacitor, or calibrated-value capacitor of another value, as described above.
5. If the reading displayed on the 3001 is within 0.1% ± 1 count, proceed to step 7; if not, go to step 6.
6. Adjust R25 until the displayed reading matches the capacitor value within 0.1% ± 1 count. This calibrates the first three ranges, and should calibrate all ranges.
7. Check the 3001 reading displayed for the 1.000 μF ± 0.1% capacitor in the 1 μF Range; for the 1000 μF ± 0.1% capacitor in the 1000 μF range; for the 10,000μF ± 0.1% capacitor in the 10 mF range; and each time, determine whether or not the reading displayed on the 3001 is within 0.1% ± 1 count of the capacitor value.
8. If calibration in step 7 is satisfactory, this completes the calibration procedure.
9. If calibration in step 7 is not satisfactory, but is close, determine the "direction" of the error; that is, whether the 3001 is reading higher or lower than the capacitor value. Also determine for which of the capacitors in step 7 the error is greatest.
10. For the capacitor in step 9 showing the greatest error, adjust R25 for half the amount of error, in the *same* direction.
11. Check again at all four checkpoints, as in steps 1 through 7, but with no further adjustment of R25.
12. If repeating this procedure does not result in satisfactory calibration, you may return the 3001 to CSC, New Haven, for factory calibration, under the terms stated in *Factory Service* (page 29).

FACTORY SERVICE AND REPAIR

Continental Specialties Corporation will service and repair your 3001 free of charge for a period of ninety (90) days. (See Warranty) Please return your 3001, shipping charges prepaid, in its original box with a copy of sales slip or original invoice to:

CONTINENTAL SPECIALTIES CORPORATION
70 FULTON TERRACE
P.O. BOX 1942
NEW HAVEN, CONNECTICUT 06509

ATTN: SERVICE DEPARTMENT

Your 3001 will be repaired, retested and promptly returned to you. If your 3001 needs servicing and is out of warranty, follow the above instructions and enclose $35.00 for Factory Service. This amount covers most routine repairs; if damage to your unit is more extensive, we will advise you of additional costs before proceeding.

WARRANTY

Continental Specialties Corporation warrants this device to be free from defective material or workmanship for a period of ninety (90) days from date of original purchase.

Continental Specialties Corporation under this warranty is limited to repairing or replacing the defective device when returned to the factory, shipping charges prepaid, within ninety (90) days from date of original purchase.

Units returned to Continental Specialties Corporation that have been subject to abuse, misuse, damage or accident; have been connected, installed or adjusted contrary to the instructions furnished by Continental Specialties Corporation or repaired by unauthorized persons will not be covered by this warranty.

Continental Specialties Corporation reserves the right to discontinue models; change specifications, price or design of this device at any time without notice and without incurring any obligation whatsoever.

The purchaser agrees to assume all liabilities for any damages and/or bodily injury which may result from the use or misuse of this device by the purchaser, his employees or agents.

Continental Specialties Corporation shall not be liable in any way for consequential damages resulting from use of this device.

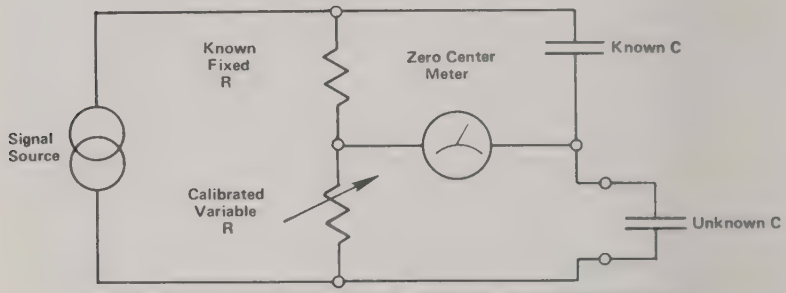
This warranty is in lieu of all other representations or warranties expressed or implied and no agent or representative of Continental Specialties Corporation is authorized to assume any other obligation in connection with the sale and purchase of this device.

APPENDIX I

INSTRUMENTATION APPROACHES TO CAPACITANCE MEASUREMENT

Over the years, many approaches have been taken to the task of accurately measuring capacitance.

Here is a review of a number of these techniques.



NULLING BALANCED BRIDGE-TYPE METER–SIMPLIFIED SCHEMATIC

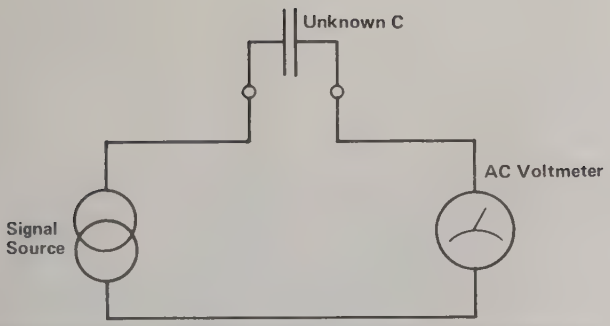
Bridge Circuits

The basic nulling balanced bridge meter instrument, suggested by Samuel Christie and Sir Charles Wheatstone in the first half of the Nineteenth Century, has been applied with increasing precision to the measurement of capacitance.

It can be demonstrated (for the bridge depicted in the illustration) that the ratio of the unknown capacitance value to the known capacitance value is the same as the ratio of values between the fixed and variable resistances. This permits calculation of the unknown capacitance by the formula:

$$\text{Unknown C} = \left(\frac{\text{Known fixed resistance}}{\text{Calibrated variable resistance}}\right) \times \text{Known C}$$

In actual practice, an AC driving signal is used, usually available at some selection of frequencies. Since practical components (unlike the ideal components of theory) demonstrate not only capacitance but resistance, inductance and other effects (indeed, these traits are also true of the test leads and the instruments themselves), a precision instrument of wide-range capability requires careful and fastidious design. As a rule, this results in a direct relationship between precision, range and price.



CAPACITIVE REACTANCE-TYPE METER—SIMPLIFIED SCHEMATIC

Capacitive Reactance Circuits

Capacitive reactance, X_C, is the property of a capacitor which determines its impedance at a given frequency and may be considered analogous to resistance.

Like a resistor, a capacitor can be used as an attentuator of an AC signal. Capacitive reactance indicates the degree to which a capacitor will attenuate a given frequency, according to the formula:

$$X_C = \frac{1}{2\pi fC}, \text{ where f is the frequency of operation.}$$

Thus, a signal of known amplitude and frequency would pass from an oscillator to an AC Voltmeter with less and less attenuation as the value of a coupling capacitance is raised; likewise, a given capacitor would attenuate less and less as the frequency is raised.

Simple instruments based on this approach have appeared in design literature for years; their accuracy, linearity and range, however, generally leave much to be desired.

Resonant Circuits

When capacitances and inductances are combined with gain elements in such a way that their reactances are equal, and that they govern the feedback of energy, we have an oscillator at a given frequency. If the inductance is known and the frequency measured, the capacitance may be determined by:

$$C = \frac{1}{L\,(2\pi f)^2}$$

This technique appears in a number of approaches. They vary from establishing the frequency of an oscillator directly; to altering the frequency of an oscillator ("pulling"); to altering the tuning of a receiver (in conjunction with a frequency standard marker oscillator, or other frequency determining equipment); to absorbing energy from an adjacent resonant oscillator (as with a grid dip meter, or any of its solid state offspring).

While these techniques are capable of reasonable accuracy, they are not generally capable of measuring a very wide range of capacitance values, and they tend to be expensive to implement.

Time Constant Approaches

A great many circuits depend on the *time constant* of a resistance in combination with a capacitance for determining a time delay or a frequency of oscillation; perhaps the most popular of these circuits is the now-famous 555 IC, although it applies to all classes of multivibrators.

In each case, a capacitance is charged to a defined Voltage, at a charging rate determined by the current-limiting effects of a series charging resistor and is approximately equal to:

$$T = RC, \text{ where } T \text{ is the } \textit{time constant} \text{ of delay.}$$

Interestingly, the units of the relationship are seconds, Farads and Ohms. This follows from:

$$\text{Capacitance (Farads)} = \frac{\text{Voltage (Volts)}}{\text{Charge (Coulombs)}}$$

$$\text{Resistance (Ohms)} = \frac{\text{Voltage (Volts)}}{\text{Current (Amps)}}$$

$$\text{Current (Amps)} = \frac{\text{Charge flow (Coulombs)}}{\text{Time (seconds)}}$$

Substituting the expression in the third formula for Current in the second, solving the second for Voltage, then substituting in the first formula:

$$\text{Capacitance (Farads)} = \frac{\text{Charge (Coulombs) x Time (seconds)}}{\text{Resistance (Ohms) x Charge (Coulombs)}}$$

Or, solving for Time:

$$\text{Time (seconds)} = \text{Resistance (Ohms) x Capacitance (Farads)}$$

This crudely defines the basis of RC time constants, as they are applied to multivibrator circuits. In practical applications, because of the nonlinearity of the charging current, the RC time constant, T, represents the time it takes for the capacitor to charge to a Voltage approximately 63% of the way between its initial Voltage and the supply Voltage.

Capacitance measurement techniques which take advantage of RC time constant charging circuits generally use a Voltage comparator adjusted to trigger at somewhat less than 63% of this Voltage interval, then scale their displayed capacitance readings to agree with standard units. In addition to the *charging circuit, discharge circuit* and *Voltage comparator* included in this class of instruments, they always incorporate some method of measuring the charge time interval.

This technique is increasingly popular, and appears in a number of versatile, inexpensive, fairly accurate and wide-range instruments now available. Most begin the charge cycle at zero Volts and incorporate a single threshold comparator.

Dual Threshold Charging Curve Approach

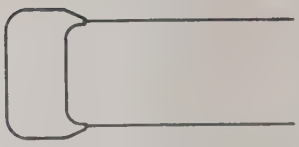
As described in the *Functional Description* section, page 12, the CSC Model 3001 Digital Capacitance Meter employs a dual threshold measurement technique.

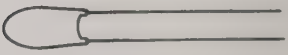
Here, the charging cycle begins at a Voltage slightly *below* zero Volts (to assure complete discharge of the capacitor) and allows the charging cycle to begin before the time measurement begins; this occurs at a *second,* lower threshold Voltage, precisely determined by a second comparator.

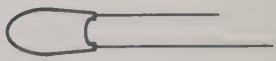
There are several advantages to this technique. First, it obviates measurement inaccuracies which result from the *dielectric absorption* of capacitors — a tendency to retain charge even with no Voltage applied. Second, since full and complete capacitor discharge is accomplished, it eliminates any errors incomplete discharging might introduce, as might occur through resistive capacitor leads. Third, it obviates any Voltage retained by virtue of the junction drop of the capacitor-discharge transistor.

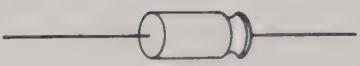
The result is greater accuracy overall, and the ability to work at lower Voltage levels with larger capacitance values, a decided safety consideration.

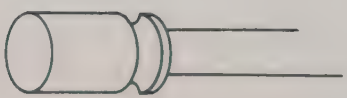
TYPICAL CAPACITOR
PACKAGE STYLES

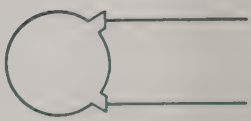












APPENDIX II

NOTES ON THE PHYSICAL PROPERTIES OF CAPACITORS

Earlier in this manual (*Applications,* page 22) we defined what we mean by capacitance:

> *An elementary electronic characteristic, resulting from basic physical principles, existing to some extent between any two conductors that are not electrically connected.*

In practical terms, we can eliminate a broad class of situations where the effects of capacitance are insigifnicant by narrowing our definition to conductors and conductive surfaces in close physical proximity to each other, and with significant parallel conductive surface areas.

Charge Storage.

The attributes of capacitance that make it electronically interesting all center around its ability to store charge.

When a Voltage is applied to a *capacitor* (which we will here define as any physical manifestation of capacitance), while no current is permitted to flow across its electrically open circuit, the electrical charge will nevertheless attract free electrons to the one conductive surface and deplete free electrons from the other. The extent of this effect depends primarily on the mutual opposing conductive surface area and on the strength, or magnitude, of the applied Voltage; secondarily, this charge level depends on the geometry of these surfaces and on the specific insulating qualities of the nonconductive material between these surfaces (called a *dielectric*).

Types of Capacitors.

All capacitors, no matter what shape or name they may possess, respond to these same principles. Differences in the dielectric materials (e.g., paper, mylar, polycarbonate, mica, ceramic), manufacturing processes, shapes, sizes and so forth provide one broad class of capacitor categories; the application to which the component is put (e.g., bypass, coupling, timing, tuning, trimming, padding, filtering, blocking) provide another.

In every case, though, the *capacitance* is defined as the charge-per-applied-Volt, as follows:

$$\text{Capacitance (Farads)} = \frac{\text{Charge (Coulombs)}}{\text{Applied Voltage}}$$

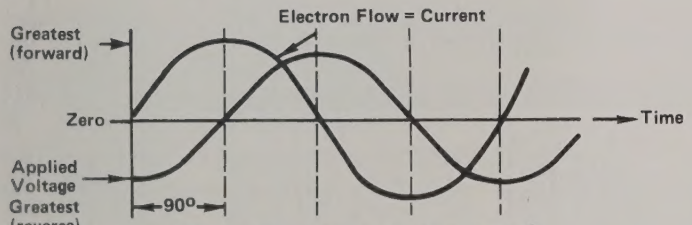
This charge storage capability, even within the same geometry, can be altered by changes in ambient temperature, humidity, radioactivity, pressure, dielectric material and other physical parameters affecting the nature of the dielectric.

Dielectrics possess only limited survival capabilities when faced with high AC or DC Voltages (just how high depends on the specific material and geometry). This is called *breakdown Voltage;* some smaller Voltage is usually specified as a *working Voltage.*

In addition, there is a tendency for dielectrics to retain some charge, even with no Voltage present across the capacitor; this is called dielectric absorption, and varies with all of the same above physical criteria.

When the applied Voltage is removed, of course, this stored charge is no longer held to the capacitor's conductive electrodes, and in returning to equilibrium causes a flow of charge out of the capacitor.

A capacitor which, when 1 Volt is applied, can store a charge of one *coulomb* (defined as approximately 6,000,000,000,000,000,000 – or 6×10^{18} – electrons) is defined as exhibiting 1 Farad of capacitance.



VOLTAGE LAGS CURRENT BY 90°

AC vs DC.

This storage and release of electrons also occurs, of course, when the polarity of the Voltage applied to the capacitor alternates. Since the electron flow (or more conventionally, *current*) in and out of each side of the capacitor reproduces the changing Voltage, AC passes through a capacitor while DC does not.

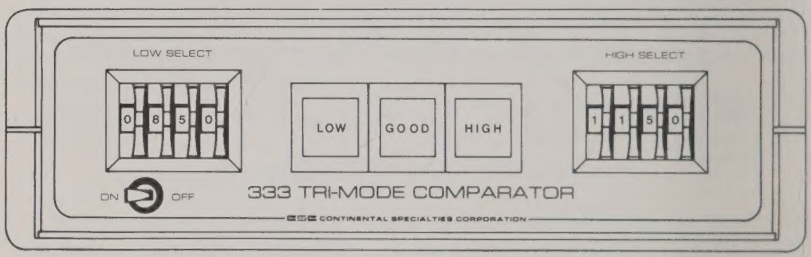
Also, the flow is least when the applied Voltage is greatest, and greatest (though in the opposite direction) when the applied Voltage is removed (or zero). In a chart of the amount of current through a capacitor versus the amount of Voltage across it, it can be seen that the cyclic variations in Voltage follow those in current. This lag is referred to as *phase shift,* and is ¼ cycle (¼ of 360°), or 90°.

APPENDIX III

OPTIONAL ACCESSORIES

Model 333 Tri-Mode Comparator

Speeds capacitor selection, sorting. Designed for use with the CSC Model 3001 Digital Capacitance Meter. Two front panel 3½-digit banks of thumbwheel switches select high and low value thresholds, corresponding to readings on 3001 display. Three outputs are offered: below low limit ("LOW"), between limits ("GOOD"), and above high limit ("HIGH"). Outputs are active-low TTL-level signals on a rear-panel DIN connector that correspond to the three front panel annunciator lamps.



INPUT: 3-lines — *Gated Clock* and *Clock Enable Gate* signals (TTL compatible, 1 TTL load), plus ground. Compatible with signals available at rear panel Interface Connector of CSC Model 3001 Digital Capacitance Meter.

RANGE: 0 - 1999 counts

LIMIT DEFINITION:
Separate front-panel 3½-decade thumbwheel switches set high, low limits. The "GOOD" condition is disabled (all lights out) if the high limit is set lower than than the low limit.

ANNUNCIATORS:
Front panel. Extended life incandescent lamps in 0.71" x 0.71" wide-angle diffuser lens assembly. Yellow "LOW", green "GOOD" and red "HIGH".

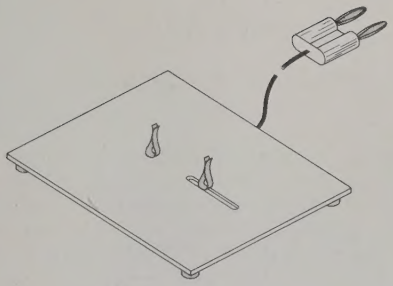
OUTPUT: Active-low 5-VDC logic, fully TTL compatible. Rated 5 TTL loads. Standard 5-pin DIN connector.

OPERATING TEMPERATURE: 0-50°C.

POWER: 8 Watts @ 105-125 VAC 50/60 Hz (220-240 VAC 50/60 Hz option available).

DIMENSIONS (HxWxD): 3 x 10 x 7 inches (76 x 254 x 178 mm).

WEIGHT: 3 lbs (1.4 kg).



Model 334 Production Text Fixture

We mounted two Test Clips on a footed aluminum baseplate to speed production applications of the 3001. Clip spacing is adjustable. Connection to the 3001 Input terminals is through shielded cable.

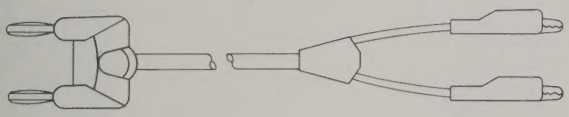
TEST CLIPS: 1.13 inches deep, with lead-capture dimple. Highly conductive nickel-plated spring brass.

SPACING: Adjusts 0.6 to 1.75 inches (15.2 to 44.5 mm) i.d.

BASEPLATE: 1/16th-inch aluminum, 4 x 6 inches (102 x 152 mm), on four insulated mounting feet. Electrically connected to ground lead of cable.

CABLE: RG-58/U coax. Terminates in 3/4-inch-spaced dual banana plug, molded tab indicates ground. 18 inches (457 mm).

WEIGHT: 6 ounces (170 gm)



Model 335 Test Cable

CABLE: RG-58/U coaxial cable, polyethylene insulation, vinyl jacket. 18 inches (457 mm).

CONNECTORS: 3/4-inch-spaced dual banana plug mates with 3001 Input terminals, molded tab indicates ground. Opposite end terminates in color-coded (red *plus*, black *minus*) vinyl-jacketed alligator clips.

WEIGHT: 4 ounces (101 gm).

Model 336 Test Clips

DESCRIPTION: Nickel-plated brass spring clips, 1.13 inches deep, mechanically and electrically attached to standard banana plug.

QU Two.

WE 3 ounces (85 gm)

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